

2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review Presentation

Fuel Cell Powered Underground Mine Loader Vehicle DE-FC36-01GO11095

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Objectives

Project Objectives

- Develop a metal-hydride, fuelcell-powered mine loader equivalent to a Caterpillar-Elphinstone R1300.
- Evaluate the vehicle in an underground mine in Nevada

Past Year Objectives

- Complete Reports Including:
 - Demonstration of an Electrolysis System for Fuelcell Mining Vehicles
 - Best Methods of Hydrogen Transfer
 - Operating Costs of Hydrogen Production
 - Ventilation Benefit Analysis for Canadian Mines
 - Cost Benefit Analysis of US Underground Mines
 - Capital and Recurring Cost Benefit Analysis for Canadian Mines

Objectives – Continued

Past Year Objectives – con't

- Determine Traction Motor
 - Induction versus Brushless Permanent Magnet (BPM)
- Determine Battery-Hybrid Configuration
 - Sizing of batteries to support duty cycle
- Determine Metal-Hydride Amount and Configuration
 - Weight limitation
- Complete Engineering Design

Budget

Phase 1	\$ 926,670
Phase 2	\$3,165,400
Phase 3	<u>\$4,525,303</u>
Total:	\$8,617,373

Total DOE Funds:	\$4,239,198	49.2%
Total NRCan Funds:	\$ 599,500	7.0%
Placer Dome Funds:	\$ 225,000	2.6%
Newmont Mining Funds:	\$ 100,000	1.2%
Total In-Kind Cost Share:	\$3,453,675	40.0%

FY04 DOE Funds:	\$1,550,000	46.7%
FY04 Contractor Funds:	<u>\$1,770,000</u>	53.3%
FY04 Total:	\$3,320,000	

Technical Barriers and Targets

- DOE Technical Barriers for Technology Validation
 - A. Vehicles
Demonstration of complete system
 - B. Storage
On-board metal-hydride storage
 - C. Hydrogen Refueling Infrastructure
On-site hydrogen production by electrolysis

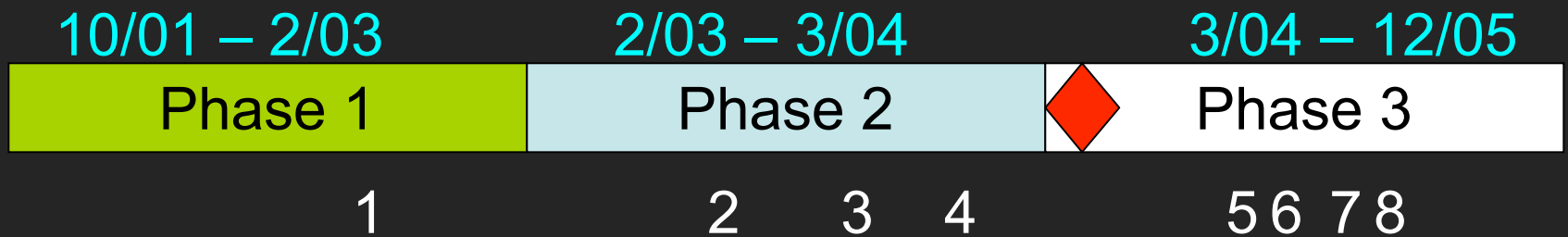
Approach

- Perform cost-benefit analysis
- Determine operational duty cycle
- Conceptual design
- Detailed engineering design
- Risk assessment
- Fabricate subsystems
- Vehicle integration and test
- Demonstration of vehicle underground

Project Safety

- Risk assessment to identify operational safety and health risks
- Individual failure mode and effects analysis (FMEA) on subassemblies
- Regulatory review including MSHA acceptance
- Lessons learned from DOE Fuelcell-Powered Underground Mine Locomotive Project Risk Assessment

Project Timeline



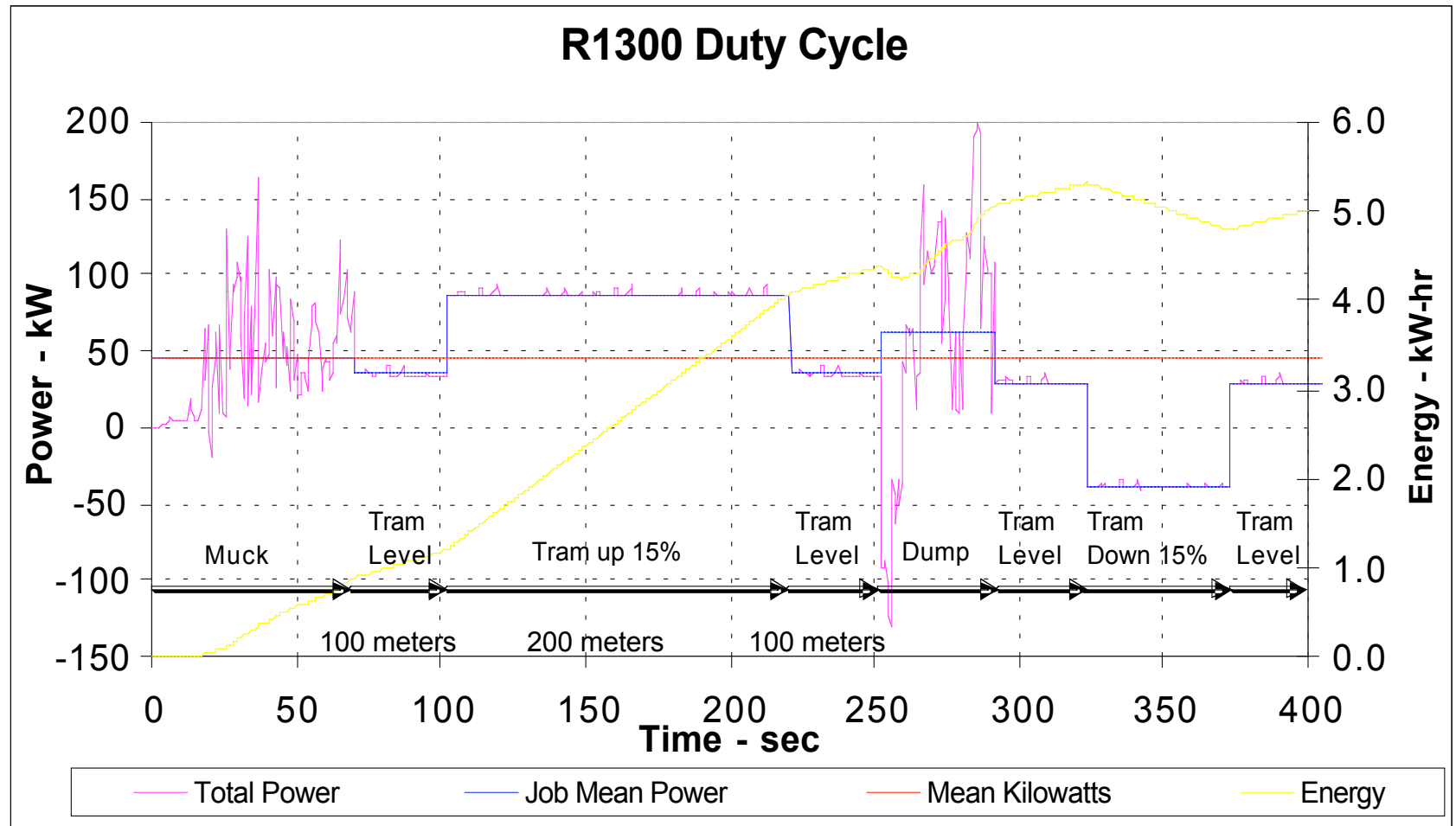
- **Phase 1- Cost Benefit Analysis and Preliminary Design**
 - 1 Demonstrate electrolyzer refueling station
- **Phase 2 – Detailed Engineering Design**
 - 2 Receive R1300 diesel loader
 - 3 Select battery-hybrid configuration and regenerative braking
 - 4 Receive 87 kW gross continuous fuelcell stacks
- **Phase 3 – Fabrication, Integration, and Demonstration**
 - 5 Deliver 150 kW battery-fuelcell hybrid powerplant
 - 6 Deliver metal-hydride storage (15kg H₂)
 - 7 Vehicle integration and test
 - 8 Underground demonstration (3 mines)

Technical Accomplishments/Progress

Detailed design includes:

- Fuelcell-battery hybrid powerplant
- 70 kW continuous, 140 kW peak (net)
- Removable metal-hydride storage
- Regenerative braking
- 340 kW (450 hp) DC BPM traction motor
- Separate 100 kW hydraulic BPM motor

Technical Accomplishments/Progress



Technical Accomplishments/Progress



Photo Courtesy Nuvera Fuel Cells Inc.

Fuelcell Stacks Manufactured by Nuvera Fuel Cells Inc.

- 87 kW gross (total)
- 290 V, 300 A full load
- Air pressure 2.0 bara
- H₂ pressure 2.2 bara
- Air stoichiometry 2.0
- Operating temp 60-75° C
- Air RH = 80-100% @ 70° C
- External air humidification
- Fuel loop dead-end mode
- Weight 280 kg
- Volume 220 L

Technical Accomplishments/Progress

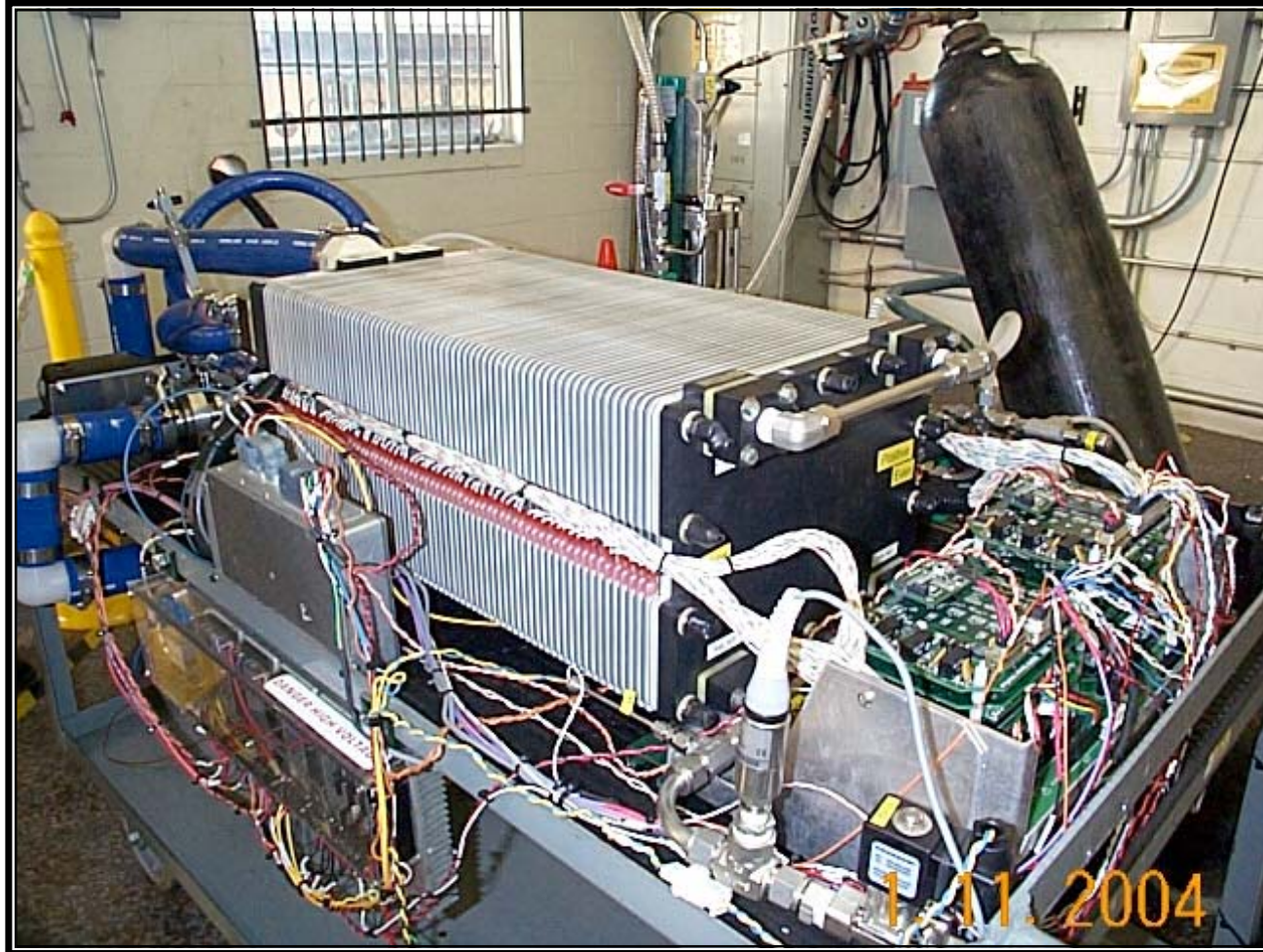
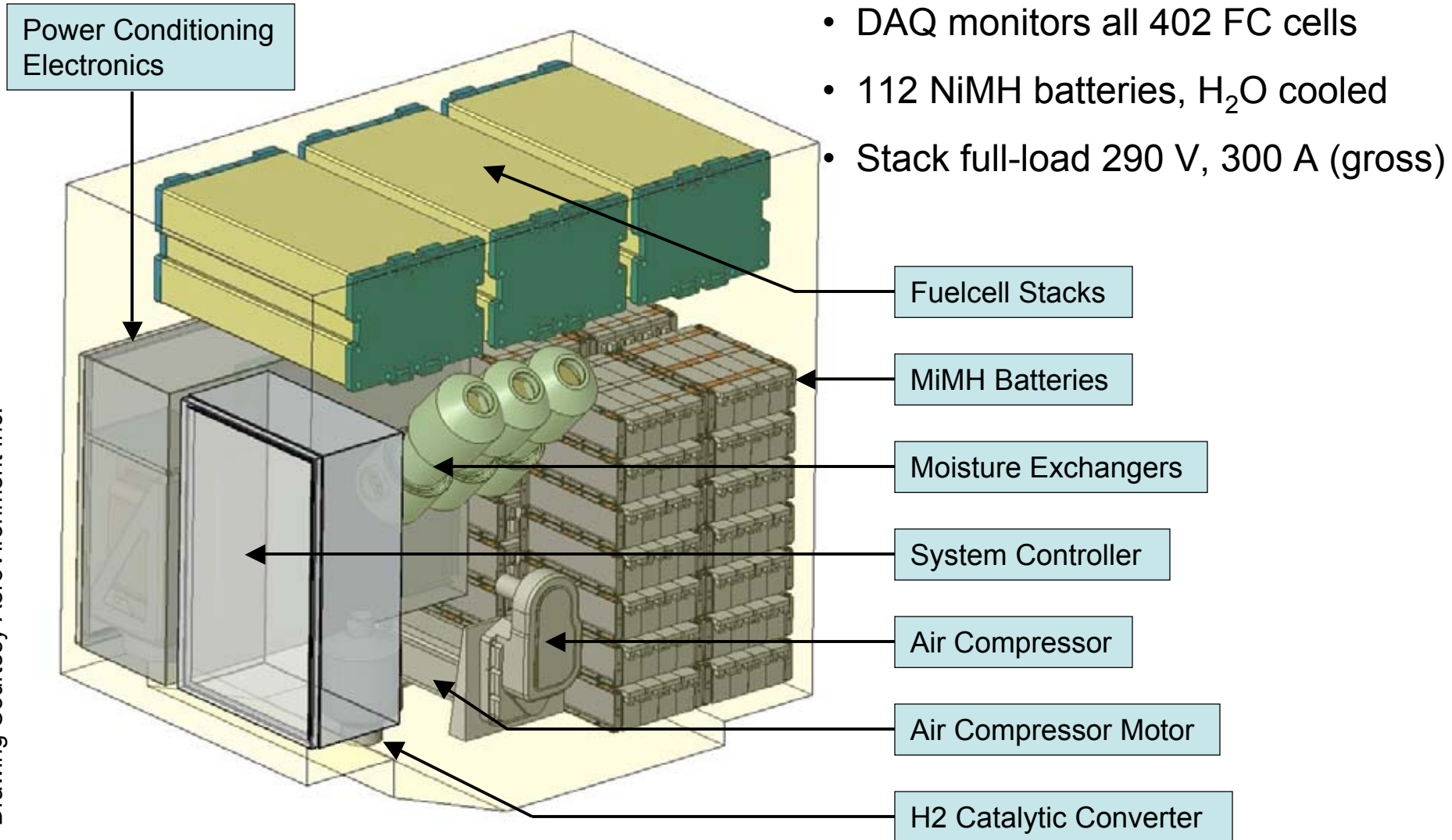


Photo Courtesy Vehicle Projects LLC

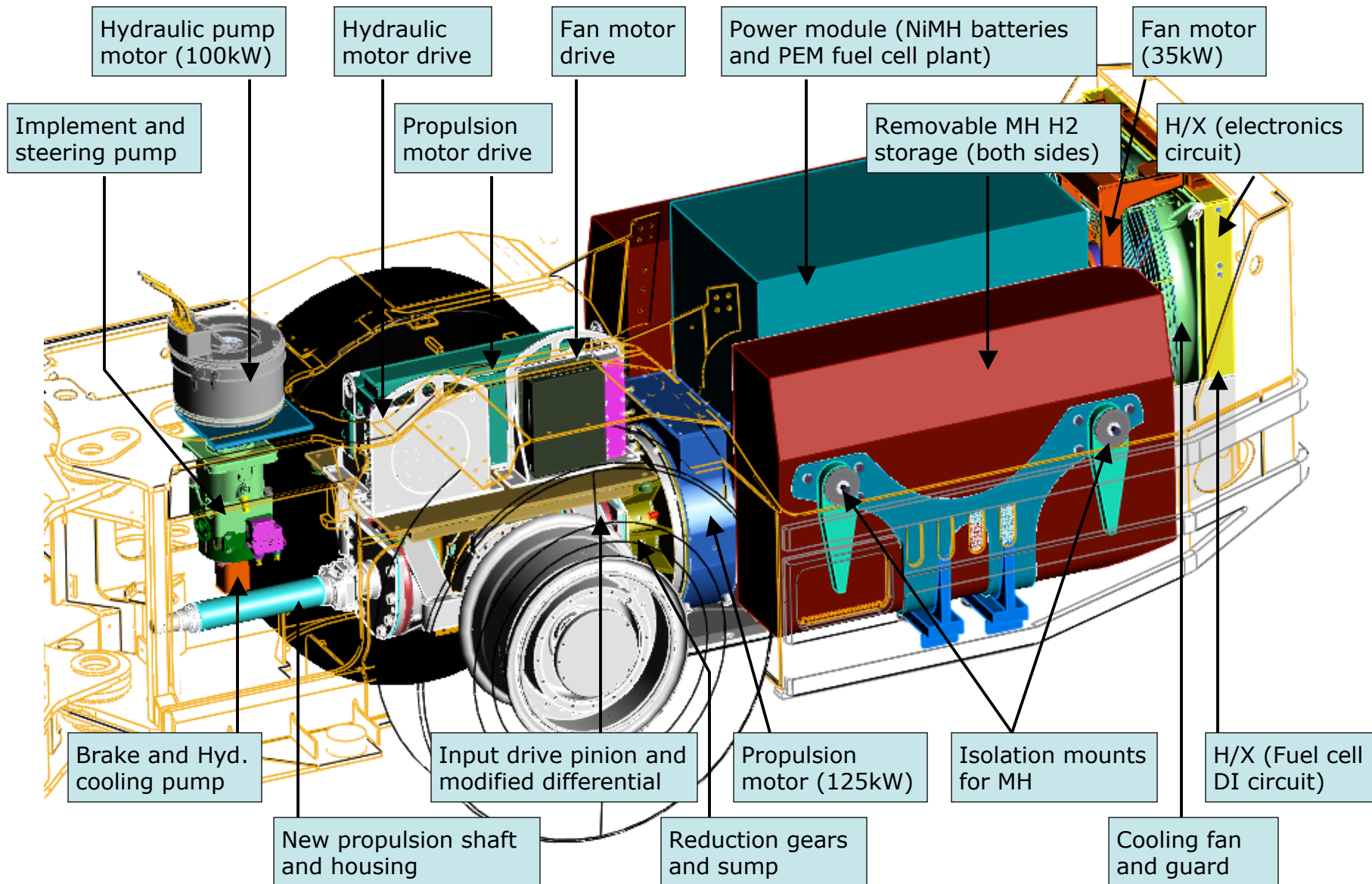
Fuelcell Stacks Bench Tested at AeroVironment Inc.

Technical Accomplishments/Progress



Drawing Courtesy AeroVironment Inc.

Technical Accomplishments/Progress



Drawing Courtesy Caterpillar Inc.

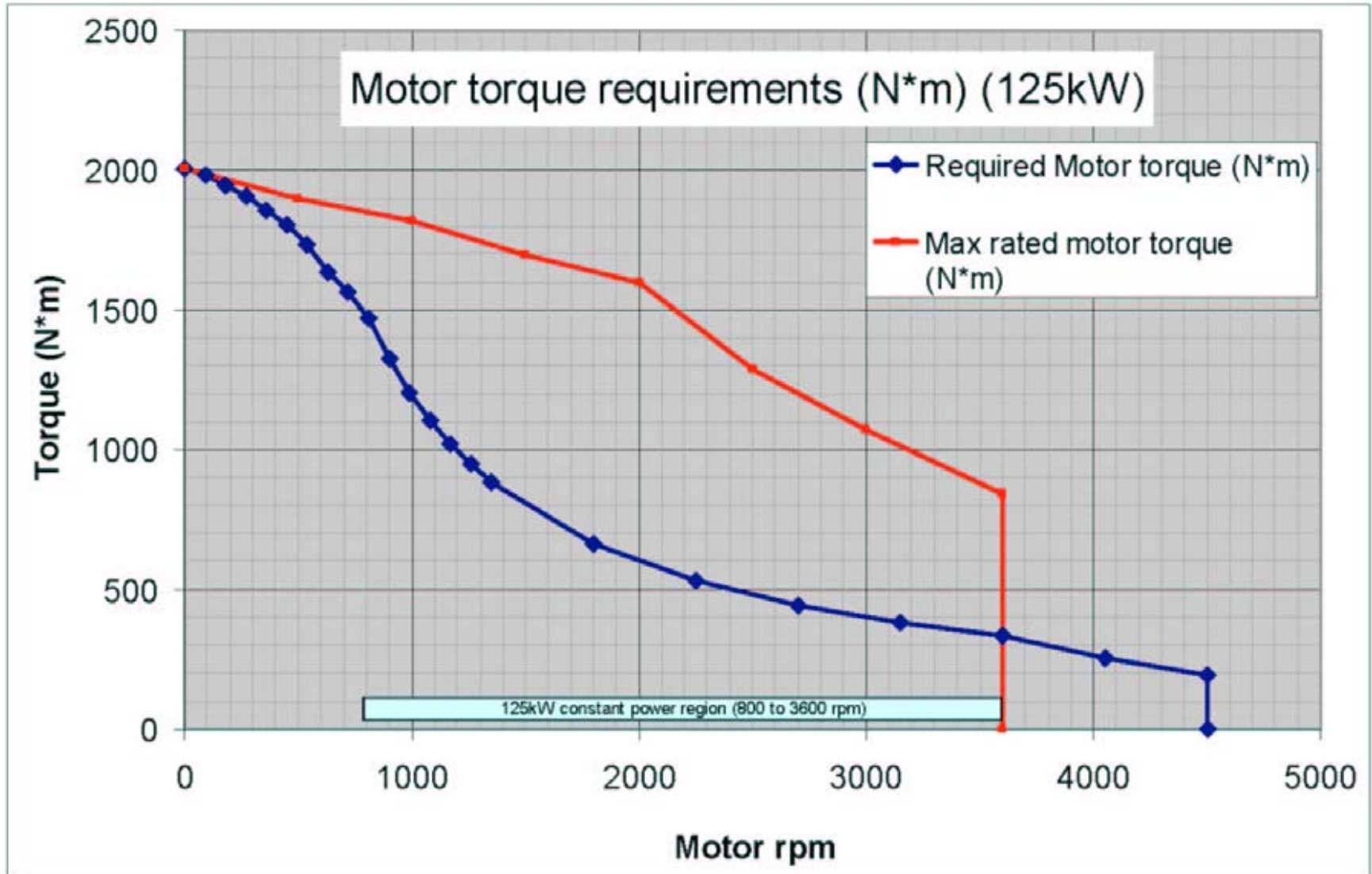
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Technical Accomplishments/Progress

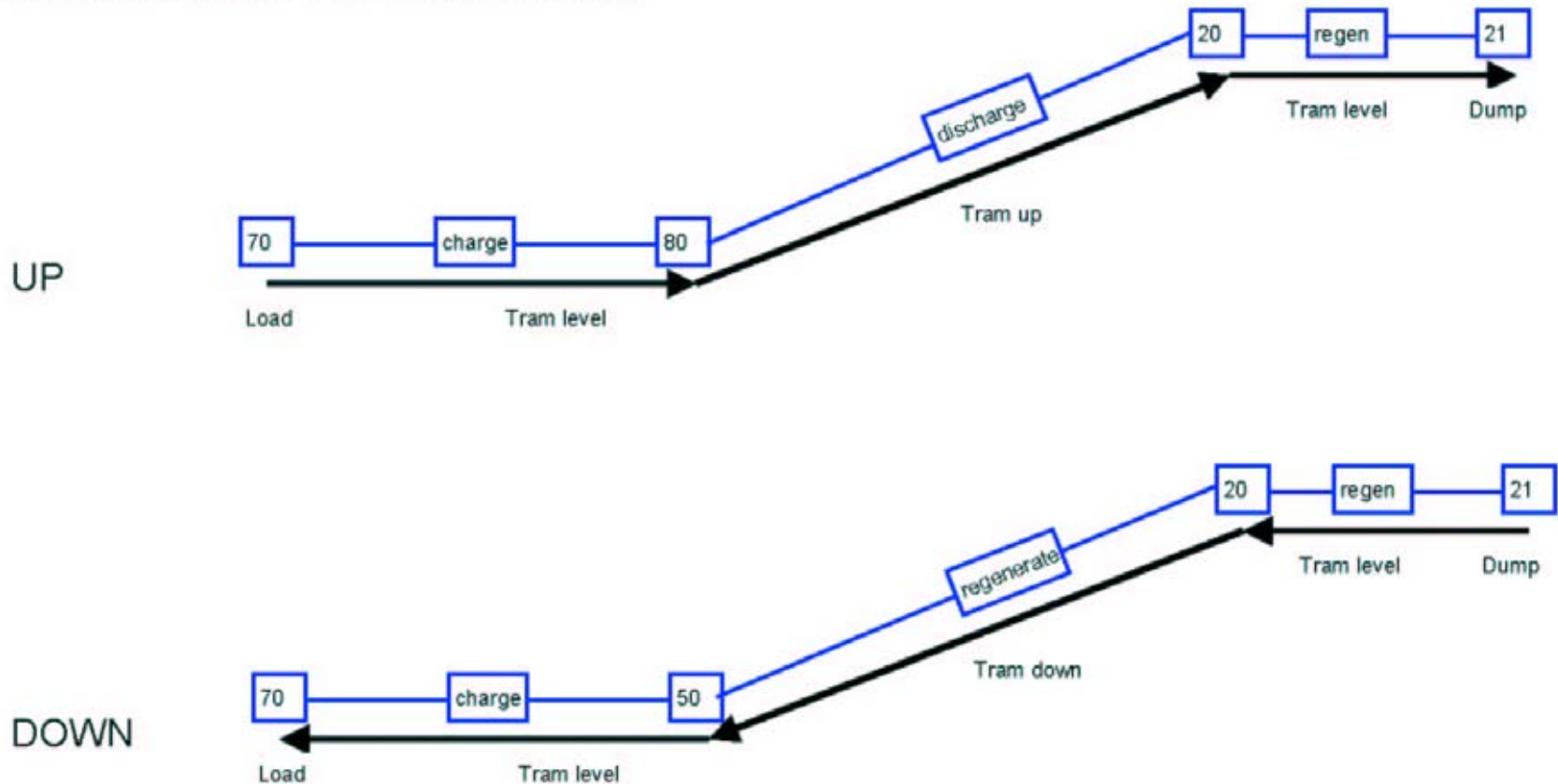
- Battery configuration
 - Cobasys (formerly Ovonics) NiMH batteries
 - Single battery rated at 12 V, 8.5 AH
 - 56 in series of 2 each in parallel
 - Module rated at 672 V, 17 AH, 11.42 kWh nominal
 - Maximum battery power up to 2 minutes will provide additional 65 – 70 kW

Technical Accomplishments/Progress



Technical Accomplishments/Progress

Assume battery is cycled from 20 to 80% during each cycle.
80% leaves head-room for regen braking.



Interactions and Collaborations

Engineering and Manufacturing

- AeroVironment Inc.
 - Caterpillar Inc.
 - Caterpillar-Elphinstone
 - DRS-Technologies
 - HERA Hydrogen Storage
 - Modine Manufacturing Co.
 - Nuvera Fuel Cells Inc.
 - Stuart Energy
- Balance of Plant
 - Vehicle Integration
 - R1300 LHD Loader
 - Traction Motor
 - Metal-Hydride Storage
 - Heating and Cooling
 - Fuelcell Stacks
 - Hydrogen Refueling Station

Interactions and Collaborations

Engineering and Consulting

- | | |
|----------------------------------|------------------------------|
| • Hatch | Risk Assessment, Regulatory |
| • Placer Dome Technical Services | End-User Oversight |
| • Southwest Research Institute | Duty Cycle / Energy Modeling |
| • WSMS | Hydrogen Risk Analysis |

Academia

- | | |
|----------------------------|------------------------|
| • University Nevada – Reno | Ventilation Evaluation |
| • Carleton University | Software Simulation |

Interactions and Collaborations

Government

- | | |
|---------------------|--------------------------------|
| • CANMET (Canadian) | Tech. Transfer, Demo Oversight |
| • MSHA | Regulatory Oversight |

End-Users

- | | |
|------------------------------|--------------------|
| • Agnico-Eagle Mines Ltd. | Mine Demonstration |
| • Newmont Mining Corporation | Mine Demonstration |
| • Placer Dome Ltd. | Mine Demonstration |

Responses to Previous Year Reviewer's Comments

Project not presented last year

Future Work

- Remainder of FY 2003
 - Fabrication/Assembly of Fuelcell Powerplant, Metal-Hydride Storage
 - Loader Teardown and Preparation
 - Test Traction Motor and Reduction Gear
 - On-going Risk Assessment and Regulatory Review
- FY 2004
 - Vehicle Integration
 - Vehicle Commissioning
 - Complete Risk Analysis and Regulatory Review
 - Underground Mine Demonstrations (3 mines)